IFM-GEOMAR

Leibniz-Institut für Meereswissenschaften
an der Universität Kiel

IFM-GEOMAR Report 2002-2004

From the Seafloor to the Atmosphere

- Marine Sciences at IFM-GEOMAR Kiel -

June 2005

Preface

For the first time, the Leibniz Institute of Marine Sciences (IFM-GEOMAR) presents a joint report of its research activities and developments in the years 2002-2004. In January 2004 the institute was founded through a merger of the former Institute for Marine Research (IfM) and the GEOMAR Research Center for Marine Geosciences. This report addresses friends and partners in science, politics and private enterprises. It gives an insight into the scientific achievements of IFM-GEOMAR and its predecessor institutes during the last three years.

3.13 Seismic Imaging of Gas Hydrates

Over the last decade, considerable attention in scientific research has been focussed on gas hydrates, i.e. gas trapped in an ice-like structure (also known as burning ice) beneath the seafloor. This interest reflects in part the large potential impact of gas hydrates on the global climate, in part the enormous amount of hydrocarbons stored in these deposits, and finally the effect of hydrates in (de-)stabilising the continental slope. The last depends on the relative importance of methane hydrates in preventing porosity loss (decreasing shear strength) and in cementing together the sediments grains (increasing shear strength). The situation is further complicated by the possibility of the dissociation of the deepest methane hydrate leading to the development of a weak zone of high porosity beneath a stronger hydrate-bearing layer, conditions ideal for the development of catastrophic landslides.

Hydrates are a natural phase of the methane-water system (and possibly other gases) in which water molecules form a cage enclosing the gas molecules. Two different types of cage formation are observed in nature: type-I is a cubic structure while type-II is of diamond shape. The second one can enclose larger molecules (e.g. Propane) but occurs less often than type-I. If completely saturated, 1 m^3 of gas hydrate would comprise of 0.8 m^3 water and 164 m^3 Methane at atmospheric pressure and temperature. Hydrates require special conditions of temperature and depth (pressure) to be stable and so only occur along the slope continental margins and permafrost regions.

Marine science first used the Bottom-Simulating-Reflector (BSR) to characterize and map out gas hydrate occurrences. During the Ocean-Drilling-Program (ODP), however, hydrate samples were taken in areas where no BSR was found. BSR represents the base of stable hydrates and is the seismic image of the interface between solid hydrate and free gas: where no free gas is present, there is no BSR even though hydrates may well be present. As the hydrate stability limit is controlled by pressure and temperature, the BSR tends to follow the shape of the seafloor, in places cutting across stratal reflections. Based on the ongoing research and results, different amounts of worldwide hydrocarbon accumulations in hydrates have been proposed. The amount postulated in the late nineties was more than twice that of the known deposits of fossil carbon ($10*10^{12}$ t), while newer estimates propose only 0.5 - 2.5 * 10^{12} t of hydrocarbon bound in the worldwide hydrate deposits. Prior to the scientific evaluation of hydrate quantify and its possible consequences, it is essential to develop methods for detailed characterization of gas hydrate deposits. Consequently, various tools have been developed and measurements taken by IFM-GEOMAR over the last few years.

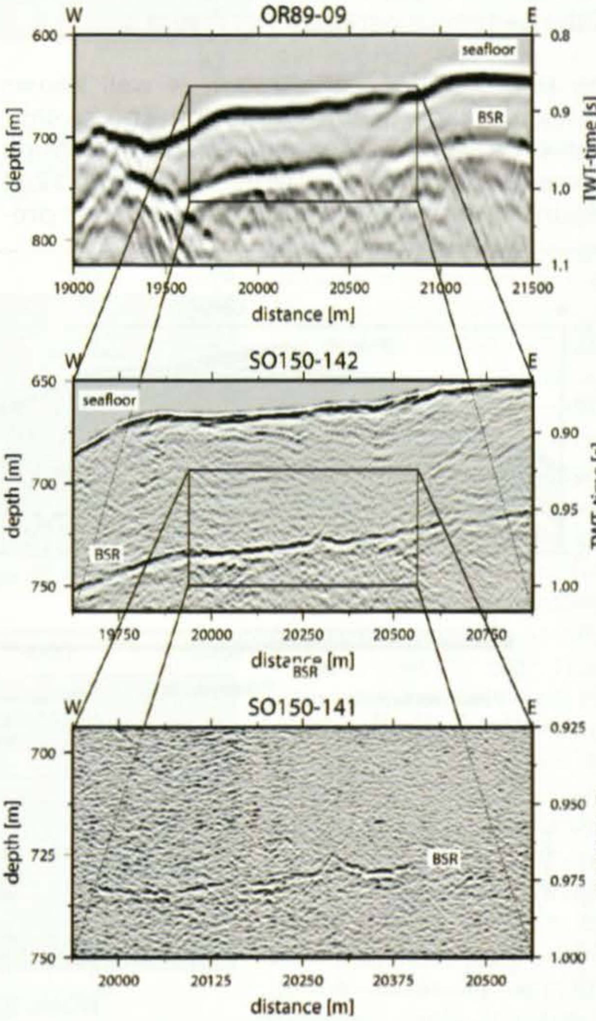

Figure 1: Multiple survey acquisition, using a surface streamer, over the same subsurface structure with different source frequencies. Main frequency: top 40 Hz, center 120 Hz, bottom 280 Hz. With increasing source frequency the image shows an increase of resolution and the BSR an increase of complexity.

Seismic image processing visualizes the subsurface structure by means of reflected acoustic signals. The seafloor signal is marked by a white/black reflection, which means that the subsurface volume is harder than the volume above (Figure 1). Expressed in acoustic terms: the acoustic impedance, the product of density and speed of sound, below the seafloor in the sediment is higher than the impedance of the water column. In contrast, the BSR is marked by a black/white reflection indicating possibly high hydrate impedance above a gas filled sediment of methane with low impedance. As the resolution of the seismic image is limited by the seismic source bandwidth and as the physical parameters describing the seismic subsurface respond are frequency-dependent, multiple surveys with different acquisition parameters are needed to get a more complete knowledge of the sediment parameters (Figure 1).

The Hydrate Ridge off Oregon is well known for its methane hydrate deposits. The seismic profile OR89-02 crosses the southern summit where ODP drilled the sites 1245 and 1244 (Figure 2). Prior to the drilling the seismic profile OR89-02 was analyzed in respect of the subsurface P-wave velocity and the BSR depth. Besides extensive high-resolution geochemical and microbiological sampling, geophysical logging tools were deployed in the drill hole to calibrate the remote sensing seismic methods. Geophysical logging confirmed that the velocities estimated from the seismic profile are quite close to in situ velocities and that the prediction of the BSR depth was accurate to a few meters (Figure 2).

Standard seismic acquisition involves towing a surface source and hydrophone behind a ship and shooting every few seconds: the energy from the source is reflected back to the surface by the different layers in the sub-surface to be detected by the streamer. However, with the continued progress in gas hydrate research the need for increased detail in investigation of such deposits and related feeder channels requires new tools and techniques. In particular, it is important to increase the resolution of the survey method, which can be achieved by lowering either the source or the receiver close to the seafloor, by using a high frequency but broad bandwidth seismic source. However such data are non-standard and require specialised and sophisticated processing techniques.

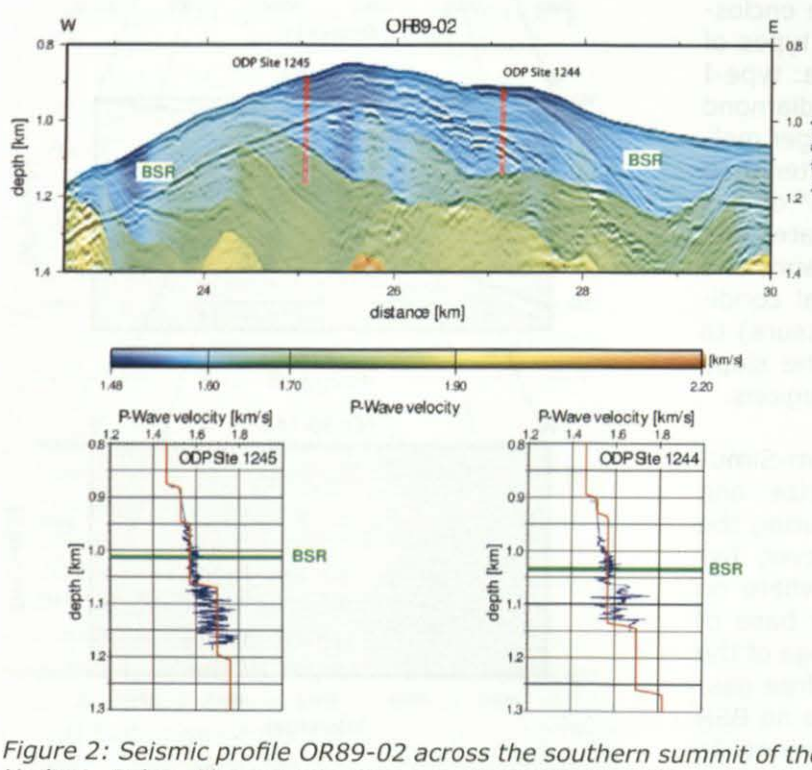

Figure 2: Seismic profile OR89-02 across the southern summit of the Hydrate Ridge. The seismic image is illuminated by the subsurface velocity determined from prestack depth migration analyses. A BSR crossing the stratigraphic sedimentary units is clearly visible. In the diagram the predicted subsurface velocity (red) and the in situ velocity (blue) at the two ODP sites 1244 and 1245 show a good agreement.

Lowering the receivers to the seafloor can be achieved through the use of ocean-bottom-seismometers (OBS). As these instruments are effectively fixed, shooting over them provides raypaths through the sub-surface over a wide range of offsets, yielding detailed information on the velocity of propagation of the seismic energy, and hence on the physical properties of the subsurface.

Using the OBS data displayed in Figure 3, estimates of the gas hydrate content were computed for these observations in the Black Sea. The hydrate content was found to be 10% - 15% of the pore volume close to the seafloor, while it increases to 35% - 40% at the BSR. These values were calculated assuming the hydrate is part of the solid phase without effecting the cementation. If it does effect the cementation, then lower values

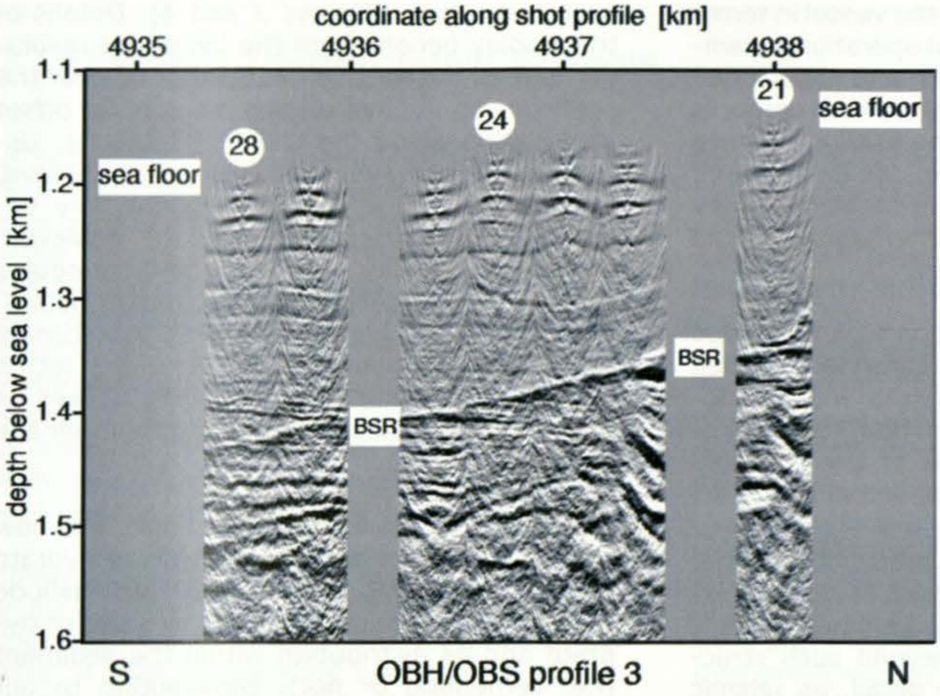

Figure 3: Kirchhoff migrated image of a BSR observed by OBS within the Dnjepr plaeo-fan, Black Sea, GHOSTDABS project 7 hydrophone channels of OBS 21 - 28 were used to image the BSR 200-230 m below seafloor.

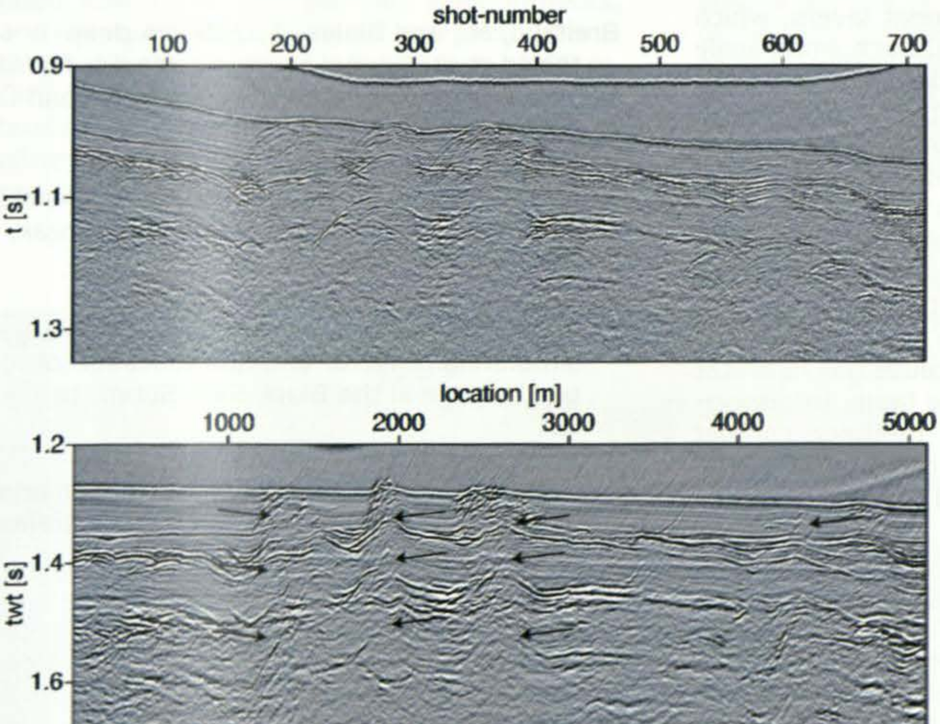

Figure 4: Pre-Stack Depth migrated seismic image of chemoherms Max & Moritz offshore Peru (display is converted to TWT). Arrows mark small scaled faults which are interpreted to represent feeder channels for upward migrating methane enriched fluids.

are obtained. In the latter case one would not expect to find hydrates down to 40 m bsf. At the BSR 25% to 30% should be expected. As well the amount of free gas underneath the BSR is calculated within a broader range of values, which varies between 1.6% - 0.1% depending on the model assumed to be applicable.

However, unless a large number of such instruments are used, the gaps between instruments results in gaps in the seismic image in the critical shallow sub-surface (Figure 3) Alternatively, it is possible to tow a hydrophone streamer close to the seafloor rather than at the sea-surface, although the necessarily limited length of such a streamer and its fixed positon relative to the source results in little information on seismic velocities and hence physical properties. As the two techniques are complementary, we have followed both strategies, developing a pool of ocean bottom seismometers for detailed determination of seismic velocity and for high resolution imaging beneath the seafloor and a deep-towed hydrophone streamer for very high resolution imaging of the shallowest sub-surface. The streamer itself is a modular design, which allows varying the offset of the single hydrophone nodes by applying different cable lengths in between. For navigational purposes the system is equipped with an ultra-short baseline acoustic navigation (USBL), which enables us to locate the front of the streamer behind the vessel in terms of azimuth and depth. Typical operation parameters are 3000 m water depth and about 6000 m length of towing cable while the streamer is towed about 100 m above the seafloor. A deep towed SideScan sonar system can be deployed simulataneously to allow back-scatter imagery of the seafloor (identifying chemoherms, fluid seeps and faults for instance).

With this receiver configuration high resolution images of gas hydrate and carbonate related structures could be investigated with resolutions not available by conventional techniques. As an example observations of the Max and Moritz chemoherms are displayed in Figure 4.

Chemoherms are carbonate precipitations that occur when Methane enriched fluids are expelled at the seafloor. With conventional seismic methods sediment layers beyond such structures cannot be resolved in detail, as seismic energy is scattered and the layers below appear as "blanking" zone. With the deep towed streamer reflecting energy could be recorded from below the structure resolving small-scaled ruptures in the sediment layers, which are continued from the sides. Such small-scale faults probably serve as feeder channel for the upward migrating fluids - this image represents the first time such conduits have been convincingly imaged beneath a chemoherm field. If such faults reach as deep as the base of the hydrate stability zone they may allow free gas from depth to pass through the hydrate stability zone, without forming gas hydrates in their vicinity. If the upward migrating fluids are heated they may cause gas hydrates deposited to the sides of the faults to dissociate again and release their methane content to the seafloor as well. The dissociation of the cementing hydrate may lead to a major destabilization of the margin as discussed above, which in turn could lead to slumping of a slope. Such high resolution imaging thus has important applications in future studies of slope stability and hazard assessment. Furthermore, the enhanced resolution of such a system also allows the BSR itself to be mapped out more thoroughly, meaning that the nature of the interface between the hydrate stability zone and underlying free gas can be constrained better.

Modern processing techniques such as prestack Kirchhoff depth migration are also necessary to make use of the close receiver spacing and compute images of the subsurface from such recordings (Figures 3 and 4). Details of the display benefit from the increased resolution due to the receiver location at or near the seafloor and the overlapped range of far offset observation along the profile (Figure 3). Using the entire wavefield information (P-wave, vertical and shear component) not only velocity-depth distributions could be achieved. Computing density, bulk and shear modulus allow to estimate further physical parameters. Computation of porosity enables to estimate the content of hydrates and free gas within the observed column of sediments, as well as the role of hydrates in cementing together the sediment.

These examples demonstrate that we now have the tools for detailed analysis of hydrate bearing sediments. Future work will include the better determination of the amount of hydrate and its distribution within the sediment (i.e. cementing or not), contributing to our understanding of these deposits and their relevance.

IFM-GEOMAR Contributions

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Flueh, E.R., Klaeschen, D., and Bialas, J., 2002: Options for multi-component seismic data acquisition in deep water. *First Break*, **20** (12), 764-769.

Zillmer, M., Flueh, E.R., and Petersen, J., 2004: Seismic investigation of a bottom simulating reflector and quantification of gas hydrate in the Black Sea. Subm. to GJI.

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